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THE SLEEPING GIANT: REINFORCEMENT SCHEDULES

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Schedule research has been the core of operant conditioning, but it is no longer an active area, at least with respect to its traditional focus of describing and explaining moment-to-moment behavior. Yet schedules are central in psychology: Not only do they establish lawful behavior, but they also play a major role in determining the effects of other variables. The reason for the decline appears to be primarily theoretical, in that the work seems not to have led to meaningful integration. The search for controlling variables brought into play by schedule specification has proven unsuccessful, and a catalog of all possible schedule effects is of limited interest. The paper reviews the reasons for the contemporary state of affairs. One prediction about future developments is that instead of revealing component variables and their modes of interaction, schedule effects will be treated as basic empirical laws. Theory will take the form of abstract statements that integrate these separate laws by reference to higher-order principles rather than by reduction to supposedly simpler component variables.

Key words: schedules of reinforcement, schedule theory

Not so long ago, schedules of reinforcement were virtually the definition of operant conditioning. They represented the major unique contribution of the behavior-analytic approach to the field of learning, and they constituted the most powerful independent variables ever seen in psychology. It seemed obvious and appropriate that they should be a primary focus of research. Yet they no longer appear to be of much interest to researchers: Goliath is sleeping. What produced the current state of affairs? An historical account of schedule research provides some perspective. It is followed by some predictions about the future.

The study of reinforcement schedules began with Skinner in the 1930s, and this work was highlighted in 1938 with the publication of *The Behavior of Organisms*. Here Skinner described periodic reconditioning (later to be known as the fixed-interval schedule), and went on to report experiments on fixed-ratio schedules as well as suggesting additional schedules (e.g., differential-reinforcement-of-low-rate, differential-reinforcement-of-not-responding, aperiodic schedules, etc.). Skinner's focus was primarily theoretical: He interpreted schedule performance in terms of the reflex reserve, differential reinforcement, and temporal discrimination. He also reported numerous intriguing observations, such as the various orders of deviation from a steady response rate, and the effects of a number of supplementary manipulations. Other researchers had become interested in schedules because of the theoretical importance of the partial reinforcement extinction effect, but Skinner's work generated an emphasis on steady-state schedule-controlled behavior.

This emphasis culminated with *Schedules of Reinforcement* (Ferster & Skinner, 1957). By this time Skinner had abandoned the reflex-reserve concept that had been central in 1938 and had become intrigued with schedules themselves. The 1957 book is properly viewed as an encyclopedia of schedules. In collaboration with Ferster, Skinner filled in a matrix of scheduling variables and produced many of the schedules known to date. Despite the common belief that the book was atheoretical, theory was not abandoned,

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although it does fade as the book progresses. It began with the view that behavior was to be interpreted as responses under the control of momentarily changing inferred stimuli. As schedule effects were reported, they were analyzed in terms of hypothetical stimulus control. Most important for subsequent thinking was the establishment of schedules as a separate subject matter to be investigated for their own sake.

Recognition of the power of schedules was manifest in *Tactics of Scientific Research,* Sidman's (1960) influential treatise on scientific method in psychology. Here, in a major contribution to methodology, Sidman suggested the use of schedules as a test of the adequacy of a laboratory. To determine if all is functioning properly, the experimenter should program a basic schedule and determine if the characteristic behavior occurs. If so, proceed; if not, something is wrong. Experimental psychology had reached the point of standard preparations that had typical effects on individual subjects. No other variables could compare. Sidman also proposed that schedules could provide a baseline for studying the behavioral effects of other variables such as deprivation, drugs, discriminative stimuli, and the like. Again, the potency of schedule effects was being recognized. At this point, it is necessary to recognize the emergence of several different orientations. A considerable number of researchers apparently felt that these awesomely powerful controllers of behavior warranted their attention. However, their particular approaches differed. The various main attitudes are reviewed in turn.

SCHEDULES AS BASELINES

One approach involved the use of schedules to generate baseline behavior used to study other variables. Sidman (1960) had argued for the appropriateness of the baseline usage, a strategy that had originated earlier in psychopharmacology (e.g., Dews, 1955). Dews' interest was in the effects of drugs on learned behavior, and he therefore studied the operation of pharmacological agents in the context of particular schedules. Whether the concern was with drugs, deprivation, reward magnitude, or discrimination, the prevailing schedule determined how the other variable operated. Nothing seemed to be schedule-independent: The giant always played an important role in the way any other manipulation exerted its influence. Dews (1963) was to say:

> No one would maintain that all mechanisms of physiology could be reduced to the laws of osmosis; yet osmotic phenomena are ubiquitous in physiology; wherever they can operate, they do; and the student of any physiological mechanism ignores osmosis at his peril. Similarly, it is suggested that schedule influences operate generally in psychology; that when these influences can operate, they will; and that a student of any problem in psychology—motivation, generalization, discrimination, or the functions of the frontal lobes—ignores the consequences of the precise scheduling arrangements of his experiments at his peril. (p. 148)

Many psychologists interested in problems other than schedules recognized this logic; others apparently ignored Dews' injunction. Witness the quantity of research on operant-Pavlovian interactions and on stimulus control that has used only variable—interval (VI) schedules. The ability of the VI schedule to produce steady response rates has obvious advantages, yet this asset is bought at the expense of limited generality. Conditioned suppression, discrimination, and stimulus generalization all are affected by the schedule used to produce and maintain responding, so conclusions yielded by VI schedules are not necessarily representative. Ignoring the role of schedules may be convenient, but the price of convenience can be conceptual inadequacy. Learning psychologists must incorporate a concern with schedules into their analyses of behavior, even if they choose not to be interested in schedules themselves. The giant does

not vanish because one might wish it would.

SCHEDULE PERFORMANCE AS AESTHETICS

A number of psychologists maintained an active interest in schedules per se. Conversations with some of these people indicated that they were and continue to be enamored of schedules because of the ability to control behavior so precisely. These schedule enthusiasts find the emergence of predictable patterns to be a thing of beauty, and they enjoy displaying the orderliness of behavior to all who will see.

The question is: Where does this enthusiasm lead? Certainly it can be conveyed to students, some of whom are likely to come to share the appreciation. More importantly, the schedule enthusiast is likely to have and to produce appreciation for the subtleties of contingencies. Not only do reinforcers control behavior, but exactly how they do so depends on the way that they are scheduled. Reinforcement is not simply an operation that strengthens a given class of behavior; it also yields complex but elegant patterns of responding. The resulting view of learned behavior in general and operant conditioning in particular is a sophisticated one that has proved especially valuable in applied behavior analysis, where one is immediately impressed by the complexity produced by administering reinforcers. The effective practitioner must be sensitive to the particulars of ongoing behavior as he or she tries to change it. At the same time, it is not inevitable that sophistication and elegance lead to new significant experiments. One can watch beautiful fixed-interval (FI) patterns emerge regularly for years, but this is not advancing knowledge of operant behavior or even of FI schedules. Something more is needed.

FUNDAMENTAL DETERMINATION

Dews' (1963) assertion about the centrality of schedules received further emphasis when Morse and Kelleher (1970) described schedules as fundamental determinants of behavior. Reinforcement schedules establish rates and patterns of responding, and these historical effects then determine how other variables modulate behavior.

> As behavior is changed by its consequences, the consequences that are effective in further modifying behavior change, too. The prime example is the development of a skill by differential reinforcement. As a skilled performance develops, subtle consequences, often generated by the behavior itself, become important in maintaining the behavior that has been shaped by differential reinforcement. Even with a repetitive response, the individual's experimental history and the behavior brought into a situation are important in determining how an environmental event will affect responding. . . . The effectiveness of an event in maintaining a sequential pattern of responding depends on the ongoing pattern of responding itself, which in turn depends on the subject's experimental history. The view that a schedule-controlled performance can be a significant determinant of subsequent behavior developed mainly from experimental results. (Morse & Kelleher, 1970, p. 140)

The initial experimental results referred to dealt with the effects of drugs on behavior. A wide variety of data showed that the behavior produced by a drug depended on the reinforcement schedule used to maintain responding. Drugs and schedules interact: The schedule-controlled pattern determines whether a given dosage of a given drug will increase or decrease response rate. Further research led to the discovery that the particular environmental event being programmed could be less important than was the schedule used to present the event. Perhaps the culmination of this research was the finding that electric shock could have the same effects on behavior as did food delivery, even in the absence of pharmacological interven-

tion. For example, if arranged to occur according to an FI schedule, either food or a strong electric shock will produce an initial pause followed by maintained responding. Neither the counterintuitive nature of shock-maintained behavior nor the inability to develop a theoretical explanation of it obviates the reality of the phenomenon. Whether response-produced electric shock suppresses or supports behavior depends on the schedule of delivery.

The power of schedules in constructing building blocks for behavior also is illustrated by work on conditioned reinforcement. A major development in showing the reality and durability of conditioned reinforcement was chained schedules, which enabled the maintained correlation of an originally neutral stimulus with an unconditioned reinforcer. This development culminated with second-order brief-stimulus schedules. In these arrangements, a sequence of requirements must be completed before an unconditioned reinforcer such as food occurs. Each component of the sequence involves a schedule specification, and each component completion results in a brief stimulus. The final component yields the brief stimulus followed by food. For example, the sequence may involve 30 FI 1-min components. Completion of each of the first 29 yields a 0.5-s light flash, and the thirtieth yields the flash and then food. Second-order schedules are schedules of schedules. In the example, because 30 FI components are required, the schedule is a fixed-ratio (FR) 30 of FI 1-min components. The most reliably maintained behavior occurs when the brief stimuli are always the same as the one paired with food, although appropriate experimental history can result in even an unpaired stimulus serving as an effective conditioned reinforcer (Marr & Zeiler, 1974). Each component reveals the pattern of responding characteristic of the prevailing first-order schedule (the fixed interval in the example). Once again, the way events are scheduled determines how another process operates.

In addition, the prevailing second-order schedule (the FR in the preceding example) has important effects. If the component behavior is treated as a unit by having a cumulative recorder tally one response when the component is completed, the pattern appropriate to the second-order schedules appears. Thus, in an arrangement in which the first sequence of 20 responses completed after 10 min produces food—an FI 10-min (FR 20) schedule—the time to complete successive ratios shortens as the interval progresses. The cumulative record resembles the pattern generated by simple fixed-interval schedules (Kelleher, 1966). These data imply that schedule-controlled sequences function as response units whose properties are affected by other experimental operations. Although the issue of response unit definition is an important one, it will not be discussed further here. The present point is simply that schedules seem to produce behavioral units. If that is so, it certainly is not surprising that schedules are critical in determining how other variables operate.

SCHEDULE RESEARCH

The importance of schedules is manifest: They pervade operant behavior, and they cannot be safely ignored at any time. Indeed, it would seem unnecessary to do further research to study their pervasiveness. The question, then, for the psychologist who recognizes their centrality and has made the decision to do research on what seems to be the most important factor in conditioned behavior is what approach to take to schedules. Two not-mutually-exclusive answers appear to have emerged. The first is the discovery of new schedules; the second is the theoretical analysis of how schedules exert their effects.

The Catalog Approach

When Ferster and Skinner (1957) published their tome, they described a wide variety of scheduling arrangements and a number of parametric values of each. However, they did not study every possible parameter of every possible schedule, so a

research path became evident. A new experiment could be performed by devising a novel schedule, or by studying parameter values that had never before been investigated. The apparent intent of such research was to generate a complete catalog of schedule effects on every possible species.

Perhaps this strategy was the single most important factor in putting schedules to sleep. The number of schedule permutations is limited only by ingenuity, and the number of parameter values approaches infinity, so it is not obvious that the catalog could ever be written. The strategy leads to no integrative principles, because each schedule is treated as a separate entity having effects that can only be reported and admired. It is the epitome of atheoretical research, and practitioners of it appeared to wear the nontheory badge proudly. But did anyone who thought about it really believe that the proliferation of schedules and species could lead anywhere? We could have a very large encyclopedia in which one could look up the effects of any schedule, but why would anyone want it? Recognize that the totally atheoretical orientation would lead to research on FR 29 schedules in pigeons, because the ratios studied to date had not included that value. And because 29 is not 25 or 30, it is a valid new schedule. Although this example is chosen deliberately to appear ludicrous, it indeed is an exaggerated case of the apparent logic that any experiment that has not been done previously is worth doing now. This is not a viable approach to science. There must be overriding principles that allow integration as opposed to treating every trivial manipulation as an equally significant contribution.

Schedule Theory

The meaningful issue is why schedules have their particular effects. Addressing it is a theoretical endeavor, whether the interpretation is couched in terms of inferred process or in terms of analysis of directly observable controlling variables. Given the intellectual history of those likely to be interested in schedules, it was not probable that they would choose the path of hypothetical process. Instead, theory took the form of attempting to identify the operative variables that schedules bring into play and which shape behavior in a predictable manner. In other words, instead of being treated as irreducible causes of behavior, schedules are considered as complex independent variables that bring into play a set of more basic controlling conditions. Research and theory, then, concentrate on describing these more fundamental variables and their mode of interaction. A given schedule may be the only way of imposing several fundamental variables simultaneously at a particular level, but it still should be possible to tease them out. This form of theoretical analysis originated with Skinner (1938) and was followed by Ferster and Skinner (1957). The most purely variable-oriented explanations are evident in Morse's (1966) chapter and in Zeiler's (1977) follow-up to it.

So many experiments are relevant to these various efforts that they cannot be discussed here. Suffice it to say that we still lack a coherent explanation of why any particular schedule has its specific effects on behavior. Some of the relevant evidence leading to this negative conclusion has been discussed elsewhere (Zeiler, 1979). Whether the explanation has been based on interresponse time, reinforcement, reinforcer frequency, relations between previous and current output, direct or indirect effects, or whatever, no coherent and adequate theoretical account has emerged. Forty years of research has shown that a number of variables must be involved—schedule performances must be multiply-determined—but they provide at best a sketchy picture and no clue as to interactive processes.

The history of psychological theory shows that variable analysis was well known before it was applied to schedules. Experimental psychologists wholeheartedly embraced the view that the basic task of science is to describe controlling variables precisely—that is, to find the empirical laws of the subject matter. In psychology, empirical laws

were hard to come by, and this difficulty was attributed to the fact that so many variables influenced a given phenomenon that orderliness was obscured by the difficulty of exerting sufficient experimental control. Theory, then, was used to help discover laws: When even apparently simple experimental situations involve too many variables to permit isolation of the role of each and description of their exact mode of interaction, hypotheses about the variables and interactions are essential in arriving at laws. Learning theory took the path of recognizing complex multiple determination by studying each purported simple controlling variable separately to obtain the function between it and behavior. When the separate variables then are combined, the assumption is that the individual functions continue to operate, but now they interact to determine behavior. Each independent function serves as an intervening variable between the environmental manipulation and behavior, and then these intervening events combine in some way to produce the observable behavior. This is exactly the theoretical situation with respect to schedule analysis. So, for example, assume that schedule-controlled behavior arises from reinforcer frequency, delayed reinforcement, level of deprivation, discriminative properties of reinforcement, and previous output. The program for research would be to study each of the five factors separately to observe the function relating each to behavior, and then to view the final behavior as due to the interaction of the five individual functions. Each separate function is an intervening variable, because none is uniquely responsible for the observed behavior occurring when all are combined. The final task is to describe the combination rules. The variable analysis of schedules involves just this logic. And, for schedules, just as has been true elsewhere in conditioning, the task of finding the precise interaction rules has not been successful. In fact, it is not always possible even to find all of the component functions. One also wonders if the effort must not lead inevitably to infinite regression, given that each presumed variable can itself only be studied in the context of a schedule that presumably would have to be analyzed itself!

A path sometimes taken within learning theory was to invoke the existence of processes internal to the organism. Such invocation has been anathema to schedule researchers, although it did occur in early theorizing. Skinner's (1938) reflex reserve was both an intervening variable (the reserve referred to the relation between number of reinforcers and the number of responses occurring in extinction) and a hypothetical process (when Skinner described certain events as disturbing or straining the reserve, the concept appeared to refer to an internal event that actually existed), and Ferster and Skinner's (1957) inferred stimuli presumably really existed. Recourse to inferred events easily yields the appearance of explanation when it really is only a verbal ploy. The history of psychology is replete with such illusions.

Spence (1944) pointed out that, in psychology, theory serves to help discover laws, whereas in other sciences in which empirical laws can be described directly, theory consists of higher-order, more abstract statements that serve to integrate separate empirical laws. Spence's discussion suggests that at the level of schedules as independent variables, intervening-variable theory is unnecessary: A given schedule has such uniform and predictable results that laws of schedules can be stated. This is no mean contribution for a science in which such precision is unparalleled. Attempts to explain *why* schedules have their effects in terms of still lower-order functional relations make no scientific sense. Unless new classes of fundamental events can be discovered (witness what DNA did for our understanding of genetic mechanisms), the more promising perspective is to try to formulate more abstract integrating principles.

THE FUTURE

As of now, schedule research, at least in a scientifically interesting form, is moribund. To all appearances, schedules are used as

tools to study "more interesting" problems, but in and of themselves are of little apparent interest. What would be essential for reactivation seem to be theoretical innovations that would provide or could at least lead to conceptual integration. In the absence of such innovations, schedules remain a tool for studying operant behavior, yet themselves go unexplained. The possibility that schedule research per se is deservedly dead certainly is possible, but maybe the blame lies with previous and current barren approaches to the area rather than with schedules themselves.

The time has come to hazard some predictions. Researchers will not continue to ignore schedules; they are too potent in determining behavior to do so. Experimenters interested in other problems sooner or later will encounter fundamental determination and then will have to face the acute need of understanding what is going on. At the same time, the intervening-variable approach to schedule theory will fade even more than it has now, at least in its traditional form. The attempt to simplify by finding what component independent variables are brought into play by a schedule specification cannot succeed because of the complexity of the interactions, and also because many of the controlling variables arise indirectly through the interplay of ongoing behavior and the contingencies. The alternative is to recognize that each schedule has its specific effects and to treat schedules as irreducible independent variables. We have, for example, The Law of Fixed-Interval Schedules and The Law of Fixed-Ratio Schedules, but we will not be able to analyze these laws at a more molecular level.

The role of theory, then, would be to integrate these laws at a higher level. What more abstract principles would relate these low-order laws? An example of a higher-order theory is Herrnstein's (1970) absolute-rate matching law. The matching law, in principle, looks across schedules to determine the overriding rule relating overall response rate in simple schedules to reinforcer frequency, and it uses this rule to encompass other issues such as preference in concurrent schedules. At this time, however, the matching law does not resolve problems of central interest to the student of schedules. Its molar orientation leads away from moment-by-moment behavior to descriptions of only overall and relative response rates. Molarity on the independent variable side is characteristic of most contemporary thinking about behavior: Probabilistic explanations that involve integration of events over time as controllers of behavior abound in the context of either operant or Pavlovian conditioning. However, the matching law's extreme molarity on the dependent variable side diverts attention from the occurrence of individual responses in time. The same appears to be true of theories taking an economic approach to behavior. The disappearance of cumulative records from experimental reports reflects the shift in focus from behavior as it occurs in real time to behavior averaged over extended time periods. This means, of course, that the classic concerns of schedule research are not treated.

Perhaps the explanation of behavioral details is impossible, and we should be pleased with our accomplishment in observing such a high degree of orderliness in overall response rate or in time allocation. After all, modern physics has shown the limitations of extreme molecularism. Yet is it possible that psychology already has reached an interdeterminacy barrier when it tries to deal with why pecks occur at certain moments in time? If, however, that point has been reached, then theories like the matching law may be doing much of what is possible. My hunch is that such a barrier does not yet confront us.

The beginnings of a fruitful orientation may be evident in attempts to reestablish learning theory in general evolutionary theory, the location in which a concern with the learning process originated. Evolutionary theory in biology took as its task the explanation of species changes and continuity as determined by environmental pressures, whereas learning theory in psychology was concerned with the forces of adaptation

within the lifetime of individuals. Somewhere along the line, the psychology of learning shifted away from this overriding biological concern to an interest in learning for its own sake. An evolutionary orientation reinstates adaptation at the core by viewing learned behavior as a way of coping with a set of environmental demands. An example appears in Collier's (1983) assertion that schedule-controlled performance represents a particular solution to the problem of foraging. Organisms have evolved in certain ecological niches, and processes also have evolved that allocate resources in ways that enhance survival. When exposed to the conditions of the experimental laboratory that commonly demand performance to obtain food, animals must cope with the environmental demands imposed on finding, obtaining, and consuming food. Their performance represents an interaction between the behavioral repertoire provided by their genetic endowments in conjunction with their personal histories and the constraints imposed by the experimenter. Collier has shown that performance under the same schedule of food delivery changes dramatically with alterations in an ecology that can be modeled in the laboratory. Schedule performance, then, is properly viewed as a foraging strategy rather than as an invariant.

Another possibility would be to view conditioned behavior as maximization of payoff. Right now these views, like Collier's, tend to focus on overall response rates and/or preference in concurrent schedules, but eventually they will prove able to deal with moment-to-moment behavior. Data showing that preference ratios in concurrent schedules can be understood as by-products of maximizing reward at each moment in time (see Shimp, 1975) led to the view that optimization operates generally in behavior. Optimality will have to be viewed in the context of temporal control, stimulus-stimulus effects, and the like. However, these will have to be incorporated within the general view of optimization rather than serving only as interacting variables.

Optimization theory shows every sign of becoming increasingly formal and mathematical (see Staddon, 1983). Traditional schedule researchers may find the approach uncongenial, and they may even reject it out-of-hand, but they provide no viable alternatives. Specific simple and compound schedules will be seen as instances of more general, yet rigorously mathematically defined, principles. In so doing, there is every possibility of an increasingly close alliance with students of animal behavior, who are providing numerous examples of the power of using optimality approaches to study foraging (see Shettleworth, 1983). The development of an integrated psychobiological approach to behavior is an exciting possibility, and optimality theory very well might provide the vehicle. It is still too early to evaluate its utility with respect to understanding schedule effects, but conversations with several researchers indicate that they now are taking it seriously and are collecting highly promising data.

Unfortunately, it seems likely that the new orientation may seem foreign because it may provide the appearance of recourse to inferred process. However, it will be wholly in the spirit of the experimental analysis of behavior. The experimental analysis of behavior entails methodological commitments involving the detailed study of individual organisms and what constitutes good data; it involves no necessary commitments as to what kind of theory is appropriate. The progress envisioned in schedule research requires that schedule enthusiasts recognize the need to view their subject as being one that is firmly embedded in biology. If that occurs, the apparently dead subject matter will turn out to be only sleeping and will be reawakened by the freeing of the experimental analysis of individual behavior from the orthogonal conceptual biases of the past.

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